Biomechanical comparison of the use of a Kirschner wire or a plate as adjunctive epicondylar fixation during lateral unicondylar humeral fracture stabilization

Coggeshall, Jason D ; Lewis, Daniel D ; Iorgulescu, Alex ; Kim, Stanley E ; Palm, Lindsey S ; Pozzi, Antonio

Abstract: OBJECTIVE: To compare the biomechanical properties of using an interfragmentary 1.6 mm Kirschner wire or a 2.7 mm reconstruction plate as adjunctive epicondylar stabilization in simulated comminuted lateral unicondylar humeral fractures stabilized with a transcondylar 4.5 mm cortical screw. STUDY DESIGN: Cadaveric biomechanical assessment. SAMPLE POPULATION: Paired humeri harvested from 9 young, skeletally mature dogs. METHODS: Simulated comminuted lateral unicondylar humeral fractures were stabilized with a transcondylar 4.5 mm cortical screw placed in lag fashion. Adjunct fixations consisting of a 1.6 mm Kirschner wire on one side, and a 2.7 mm reconstruction plate on the contralateral side, were tested within paired humeri. Repaired humeri were axially loaded to failure and construct stiffness, yield load, and load to failure were obtained from the load-deformation curves. RESULTS: Stiffness (mean ± SD: 577 ± 245 vs 310 ± 71 N/mm; P = .01), yield load (mean ± SD: 2389 ± 572 vs 1017 N ± 292; P = .0002), and load at failure (mean ± SD: 3351 ± 358 vs 1693 ± 363 N; P = .009) were greater in constructs incorporating a reconstruction plate rather than a Kirschner wire. CONCLUSION: Our results support the recommendation for adjunct fixation of comminuted lateral unicondylar humeral fractures with an epicondylar plate.

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Biomechanical Comparison of the use of a Kirschner Wire or a Plate as Adjunctive Epicondylar Fixation during Lateral Unicondylar Humeral Fracture Stabilization

Jason D. Coggeshall, DVM[1]; Daniel D. Lewis, DVM, DACVS[1,2]; Alex Iorgulescu, BS[1]; Stanley E. Kim, BVSc, MS, DACVS[1,2]; Lindsey S. Palm[1]; Antonio Pozzi, DMV, MS, DACVS, DACVSMR[1,2]

From the Comparative Orthopaedic and Biomechanics Laboratory[1], the Department of Small Animal Clinical Sciences, College of Veterinary Medicine[2], University of Florida, Gainesville, FL

Work performed in the Comparative Orthopaedics and Biomechanics Laboratory, University of Florida, Gainesville, FL

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Dr. Coggeshall's current address is NorthStar Vets, 315 Robbinsville-Allentown Rd., Robbinsville, NJ, 08691

Abstract

Objectives: To compare the biomechanical properties of using an interfragmentary 1.6 mm Kirschner wire or a 2.7 mm reconstruction plate as adjunctive epicondylar stabilization in simulated comminuted lateral unicondylar humeral fractures stabilized with a transcondylar 4.5 mm cortical screw.

Study Design: Cadaveric biomechanical assessment.

Sample Population: Paired humeri harvested from nine young, skeletally mature dogs.

Methods: Humeri with a simulated comminuted lateral unicondylar humeral fracture were stabilized with a transcondylar 4.5 mm cortical screw placed in lag fashion. Supplemental fixation, either a 1.6 mm Kirschner wire or a 2.7 mm reconstruction plate, was alternated between paired humeri. Humeri were axially loaded to failure and construct stiffness, yield load and load to failure were obtained from the load-deformation curves.

Results: Stiffness (mean ± SD: 577 ± 245 vs. 310 ± 71 N/mm; $p=0.01$), yield load (mean ± SD: 2,389 ± 572 vs.1,017 N ± 292; $p=0.0002$) and load at failure (mean ± SD: 3,351 ± 358 vs. 1,693 ± 363 N; $p = 0.009$) were significantly greater for the reconstruction plate constructs than the Kirschner wire constructs.

Conclusions: Our results corroborate the recommendation of using an adjunctive epicondylar plate when stabilizing lateral unicondylar humeral fractures with comminution of the lateral epicondylar crest.

Introduction

Lateral unicondylar humeral fractures account for 36% of distal humeral fractures and 57% of humeral condylar fractures in dogs.[1] Fractures involving the lateral portion of the humeral condyle are typically ascribed to shear forces generated by eccentric loading of the capitulum by the radial head.[1–7] The capitulum is positioned lateral to the anatomic axis of the humerus and is weakly supported by the lateral epicondylar crest, predisposing dogs to sustaining lateral humeral condylar fractures as a result of minor indirect trauma.[2, 4–6, 8] A recent retrospective study reported that epicondylar comminution exists in 35.6% of lateral unicondylar humeral fractures.[6]

Lateral unicondylar humeral fractures have traditionally been managed by anatomic reduction and placement of an interfragmentary screw inserted in lag fashion.[9–12] In addition to transcondylar screw placement, most surgeons stabilize fractures of the lateral epicondylar crest with either an interfragmentary Kirschner wire[3–6, 11–13] or a bone plate.[6, 9, 14] In fractures in which there is comminution of lateral epicondylar crest, plating has been advocated in lieu of a supplemental Kirschner wire to reduce the cyclic stress on the transcondylar screw and mitigate the potential for screw failure.[6, 8, 9] In a retrospective study evaluating lateral unicondylar humeral fracture repairs in 132 dogs, major post–operative complications were more common in dogs in which transcondylar screw stabilization was supplemented with a epicondylar Kirschner wire than in dogs in which the transcondylar fixation was supplemented with an epicondylar plate.[6] These findings support the contention that an adjunctive epicondylar plate should be utilized in dogs.[6]

Despite several clinical reports which advocate the use of a supplemental lateral epicondylar plate following intracondylar screw placement[6, 8, 9] a direct mechanical comparison between placement of an adjunctive plate or a supplemental Kirschner wire has not been reported. The objective of this study was to assess the biomechanical properties of two adjunctive fixation modalities in simulated lateral unicondylar humeral fractures with a comminuted lateral epicondylar crest stabilized with a transcondylar 4.5 mm cortical screw placed in lag fashion. We hypothesized that placement of a supplemental plate would result in the construct having superior stiffness, as well as a higher yield load and load at failure in comparison to constructs with an adjunctive Kirschner wire.

Materials and Methods

The University of Florida's Institutional Animal Care and Use Committee approved the protocol for this study. Humeral osteotomies and transcondylar screw placement were modeled after studies reported by Vida, et al.[15], Rochereau, et al.[16], and Coggeshall, et al.[17]

Specimen Procurement

Paired humeri were harvested from nine young, skeletally mature dogs (weighing 20–30 kg) that had been humanely euthanized for reasons unrelated to this study. Humeri were disarticulated and soft tissue removed. Craniocaudal and mediolateral radiographs of each specimen were obtained to evaluate skeletal maturity as well as exclude specimens with skeletal pathologies. Specimens were wrapped in gauze soaked in 0.9% NaCl solution and stored at –20°C until further preparation.

Construct Preparation

Humeri were thawed to room temperature the day of mechanical testing and contralateral humeri from each dog were randomly assigned to fixation groups. The proximal portion of the humerus was removed by performing a complete transverse humeral osteotomy at the distal aspect of the humeral head using a reciprocating autopsy saw (BD040, Mopec, Detroit, MI). Each humerus was then placed in the center of a 60.0 mm long and 50.8 mm diameter segment of polyvinyl chloride piping. The humeri were positioned vertically in the pipe, with the transected surface of the humeri dependent and embedded in a styrene–acrylic polymer (Bondo, 3M, St. Paul, MN). Four screws were placed through the piping and engaged the humeri for additional stability.

The transcondylar hole for the screw was prepared prior to performing an intracondylar osteotomy. A 1.1 mm Kirschner wire was inserted from lateral-to-medial through the center of the condyle. The Kirschner wire was inserted and exited the condyle slightly cranial and distal to the eminence of the lateral and medial epicondyles. A 2.7 mm cannulated drill bit was used to over-drill the Kirschner wire. This hole was subsequently enlarged with a 3.2 mm drill bit. The capitulum was then over-drilled with a 4.5 mm drill bit to the depth of the intracondylar osteotomy. The depth of the hole was measured and tapped.

In constructs stabilized with an anti-rotational Kirschner wire, a 1.1 mm Kirschner wire was used to drill a pilot hole following preparation of the transcondylar screw hole. The Kirschner wire was inserted on the distal aspect of the epicondylar crest and advanced proximally in the medullary cavity of the epicondylar crest until it exited the medial cortex of the humeral diaphysis. The 1.1 mm Kirschner wire was removed before preparation of the condylar osteotomy and epicondylar ostectomy.

For constructs stabilized with the 2.7 mm reconstruction plate, contouring of the plate as well as screw hole preparation was completed prior to performing any osteotomies. The plate was placed along the lateral epicondylar crest positioning two screw holes distal to the planned transverse ostectomy gap, one screw hole bridging the gap, and three screw holes proximal to the gap. The holes for the 2.7 mm screws were drilled using a 2.0 mm drill bit, measured and tapped.

A reciprocating autopsy saw fit with a 0.68 mm blade (BD113, Mopec, Detroit, MI) was used to create a consistent sagittal osteotomy at the intracondylar groove, perpendicular to the medial–to–lateral epicondylar axis. The sagittal osteotomy extended 10 mm proximal to the medial extent of the supratrochlear foramen. Two parallel transverse osteotomies were performed to remove a 1 cm segment of the lateral epicondylar crest: the proximal osteotomy terminating at the proximal extent of the supratrochlear foramen. The intracondylar osteotomy was stabilized with a single non-self-tapping, threaded, 4.5 mm cortical screw. All transcondylar screws were placed in lag fashion and tightened by hand.

Following transcondylar screw placement, the adjunctive stabilizing implant was placed. For the Kirschner wire construct, a 1.6 mm Kirschner wire was advanced through the 1.1 mm pilot hole until the wire protruded through the medial cortex of the distal humeral diaphysis. In the reconstruction plate constructs, five 2.7 mm bicortical screws were placed through the five pre-drilled and tapped screw holes to secure the plate to the humerus. The most distal screw was placed to exit caudally at the distolateral extent of the supratrochlear foramen. The second most distal screw exited at the distal extent of the supratrochlear foramen just proximal to the articular surface. The third distal hole was left empty. The three proximal screws were bicortical screws and were inserted perpendicular to the plate. Craniocaudal and lateromedial radiographs were taken following construct preparation to verify appropriate implant placement and verify that no inadvertent fractures had been induced during implant insertion (Fig 1).

Mechanical Testing

The potted humeri were fixed into an aluminum jig used to mount the construct on the load cell of a mechanical testing machine (Minibionix, MTS Systems Corporation, Eden Prairie, MN). The axial load cell capacity of this testing machine is 25 *kN* / 5.5 kip. The jig was positioned so that the hydraulic actuator would apply load proximally to the distal articular surface of the capitulum. An 8.0 mm stainless steel hex socket head, that could not shift or move on the articular surface of the capitulum when the load was applied, was screwed into the hydraulic actuator and rested on the capitulum. The actuator was lowered at a constant rate of 1.0 mm/sec until 10.0 mm of displacement or construct failure was evident based on a precipitous drop in the sustained load on the load-displacement curves. All testings were videotaped (Fig 2 &3) and craniocaudal and lateromedial radiographs (Fig 4) were obtained following testing to assist in determining the modes of failure.

Data Collection

During mechanical testing, load and displacement values were recorded at a rate of 100Hz. These values were used to create load–displacement curves to determine the stiffness, yield load, and maximum load for each construct. The slope of the initial linear portion of the load-displacement curve was used to determine the construct's stiffness. Using a 0.2% offset criterion the yield point was defined as a deviation from the initial linear portion of the curve. The load at failure was defined as the highest load recorded during mechanical testing, immediately prior to a sudden decrease in the sustained load due to construct failure.

Statistical Analysis

Construct stiffness, yield load, and maximum load at failure were compared between fixation techniques using paired Student's t–tests. Significance levels were set to

$p \leq 0.05$.

Results

None of the implants in any of the constructs fractured completely during testing. The transcondylar screw in the Kirschner wire constructs either bent (3/9) or the lateral aspect of the screw was displaced proximally without bending (6/9). Kirschner wires (Fig 2) migrated (6/9) and underwent lateral bending in the ostectomy site (3/9). During loading, there was separation of the articular surface in 8/9 of the Kirschner wire constructs resulting in an intracondylar gap as the proximal portion of the capitulum displaced proximally, caudally and medially. Four Kirschner wire constructs developed distal medial metaphysis humeral fractures that propagated from the proximal aspect of the ostectomy (3/9) or the proximal articular surface of the capitulum (1/9).

The transcondylar screw in the reconstruction plate constructs (Fig 2) either bent (4/9) or the lateral aspect of the screw was displaced proximally (5/9), similar to what was observed in the Kirschner wire constructs. All reconstruction plates exhibited some degree of implant deformation (9/9). During loading, the capitulum primarily displaced proximally and slightly cranially without separation at the osteotomy in the 8/9 reconstruction plate constructs. The majority of the plate constructs had radiographic evidence of fractures involving the articular surface (5/9) and one specimen developed a spiral fracture of the distal medial metaphysis at the level of the ostectomy.

Stiffness was significantly greater ($p=0.01$) for the reconstruction plate constructs (mean ± SD: 577 ± 245 N/mm) than the Kirschner wire constructs (310 ± 71 N/mm). Yield load was significantly greater ($p=0.0002$) for the reconstruction plate constructs

(2,389 ± 572 N) than the Kirschner wire constructs (1,017 ± 292 N). Load at failure was also significantly greater ($p=0.009$) for the reconstruction plate constructs (3,351 ± 358 N) than the Kirschner wire constructs (1,693 ± 363 N).

Discussion

Our results support our hypothesis that application of an adjunctive reconstruction plate would be biomechanically superior to placement of a supplemental Kirschner wire in a humeral condylar fracture model simulating comminution of the lateral epicondylar ridge, as we found the reconstruction plate constructs had a higher stiffness, yield load, and load at failure.

Stiffness represents the initial fixation characteristics of the implant-bone construct, particularly in conditions of bridging plate fixation, as was employed in our model. In the current study, the Kirschner wire constructs had a significantly lower stiffness than the plate constructs. This reduced stiffness is attributed to the lower area of moment of inertia of the Kirschner wire and the different fixation mechanics afforded by a small diameter wire compared to a plate. Area moment of inertia (*I*) can be used to characterize an implants tendency to resist bending and stress, and ultimately an implant's stiffness.[18] The area moment of inertia of the solid cylindrical Kirschner wire can be calculated using the following equation: $I = \pi r^4/4$; with *r* being the radius of the Kirschner wire (0.7874 mm).[18] The calculated area moment of inertia of the Kirschner wire is 0.301 mm^4. Area moment of inertia of the solid reconstruction plate can be calculated using the following equation: $I = bh^3/12$; *b* being the base of the plate (5.6 mm at the narrowest width of the plate and 9.8 mm at the widest width of the plate) and *h* being the height (2.3 mm).[18] The area moment of inertia of the reconstruction plate is an estimate due to the fact that the reconstruction plate is not a uniform solid rectangular bar in addition to having scalloped borders. The reconstruction plate's area moment of inertia is estimated to be 150.94 mm^4, 500 times larger than the area moment of inertia of the Kirshner wire. This large difference in area of moment of inertia between the two implants makes our findings of a higher stiffness, yield load, and load at failure for the plate construct predictable.

We used reconstruction plates in this study because these plates could be readily contoured to conform to the irregular topography of the lateral epicondylar crest.[9] Although Kirschner wires and reconstruction plates are both forged from 316L stainless steel, the alloy used in reconstructive plates does not undergo extensive cold working.[19] Reconstruction plates were developed for mandibular reconstruction following extensive bone resection in human patients with oral tumors.[20, 21] The plates are left in the annealed, malleable condition to facilitate multidimensional contouring.[19, 22]

Bone plates employed as bridging fixation must be effective in counteracting compressive, shear, torsional, and bending forces.[23] Six-hole reconstruction plates used in this study, but a screw as not placed in the hole positioned over the segmental bone defect: bending of the implant was primarily confined to this unsupported region of the plate. Other types of plates have been used to stabilize lateral unicondylar humeral fractures with comminution of the lateral epicondylar crest, including veterinary cuttable plates, string of pearls plates, dynamic compression plates, and locking compression plates.[6] While our study did not evaluate these alternative plate types, more profound biomechanical differences would be expected if plates with greater stiffness had been used for supplemental fixation. Filipowicz et. al. demonstrated that fixed-angle locking plates were biomechanically superior to conventional compression plates in a supracondylar humeral fracture model axially loaded to acute failure. Locking plates, however, were biomechanically inferior to the compression plate when constructs were cyclically axially loaded to failure in this same study.[24]

Placement of a supplemental Kirschner wire to provide rotational stability to the capitular segment by providing a second point of fixation is a relatively quick and simple procedure. The effectiveness of a supplemental Kirschner wire, however, may be limited when there is comminution because a Kirschner wire does not confer resistance to axial compression.[1, 3, 4, 8, 12] In our model, the Kirschner wire constructs exhibited bending and proximal migration when axially loaded. The presence of compressive stress on the lateral side and tensile stress on the medial side of the capitular segment became more apparent as the capitulum segment torqued away from the intercondylar osteotomy, migrating proximally along the Kirschner wire in 5/9 these constructs. We attribute this mode of failure to the inability of an intramedullary pin to withstand the compressive force across the ostectomized site of the lateral epicondylar crest leading to pin migration along the path of least resistance. The inability of a supplemental Kirschner wire to resist the compressive forces across the simulated fracture gap in our model is highlighted by the significantly lower stiffness (46.3%), yield load (57.4%), and load at failure (49.5%) in comparison to the constructs stabilized with a supplemental epicondylar plate.

The reconstruction plate limited rotation of the capitulum around the transcondylar screw's axis,[25] providing additional stiffness and redistributing axial loads that would normally stress the transcondylar screw. All of the constructs with supplemental reconstruction plates exhibited plate deformation and in 8/9 of the reconstruction plate constructs, the capitulum displaced primarily proximally, with the incised osseous surfaces of the condyle remaining in contact. The mechanical explanation for this mode of failure is complex and has not been observed in vivo.[9, 14]

Our study has a number of limitations. First, we only submitted the constructs to acute load to failure mechanical testing. While stiffness values and yield loads support the biomechanical advantages of supplemental plating, the failure loads were supraphysiological, suggesting that both constructs may perform acceptably *in vivo*.[15, 16] The load transmitted through a dog's elbow while walking (0.8–1.0 m/s) is reportedly 60% of body weight.[26] The body weight of the heaviest dog that we harvested was 30.0 kg, which corresponds to a predicted load of 171.0 N through the dog's elbow at a walk. Mean yield loads for the constructs stabilized with a transcondylar screw and a reconstruction plate or a transcondylar screw and a Kirschner wire are 14 and six times greater, respectively, than the estimated loads at a walk. It is unlikely that acute plastic deformation of either construct would be observed at these estimated physiologic loads. Long-term cyclic loading under physiological loads would better mimic in vivo conditions and subject the implants to cyclic fatigue and micromotion.

We also chose to excise the epicondylar crest[15, 16] and only load the capitulum in this study to specifically isolate the fixation during biomechanical testing[15–17]; however, our testing methodology likely simplified the normal physiologic load distribution. Our biomechanical testing protocol also loaded the constructs beyond clinical failure. Although what degree of articular or condylar displacement constitutes clinical failure has not been explicitly agreed upon, many of the test constructs were loaded to catastrophic osseous failure. Despite supraphysiologic loading, the failure modes of many of the constructs mirrored reported clinical complications, specifically Kirschner wire migration and transcondylar screw deformation or displacement,[6, 8, 10, 11, 27, 28] which builds confidence in applying our *in vitro* results to actual clinical cases.

While placement of a transcondylar screw can provide interfragmentary compression of an anatomically reduced lateral humeral condylar fracture, our results show that application of an adjunctive reconstruction plate offers significant biomechanical advantages over placement of an adjunctive anti-rotational Kirschner wire. Our results corroborate the recommendation of using an adjunctive epicondylar plate when stabilizing lateral unicondylar humeral fractures with comminution of the lateral epicondylar crest.[9, 14] Further biomechanical studies are needed to evaluate the effects of long-term cycling and fatiguing of condylar implants as well as alternative types of plates employed as supplemental stabilization in lateral unicondylar humeral fractures with comminution of the lateral epicondylar crest.

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Fig 1. Radiographs of (A&B) a Kirschner wire and (C&D) a reconstruction plate construct prior to mechanical testing.

Figure 2. Images captured from videotaping of a Kirschner wire construct (A) before, (B&C) during and (D) at the end of mechanical testing. Note that during loading, there is proximolateral displacement of the capitular segment resulting in separation of the condylar segments at the osteotomy. Progressive axial loading results in angular displacement of the transcondylar screw as well as bending and proximal displacement of the Kirschner wire.

Figure 3. Images captured from videotaping of a reconstruction plate construct (A) before, (B&C) during and (D) at the end of mechanical testing. Note that during loading, there is proximal displacement of the capitular segment but little separation of the condylar segments at the osteotomy. Progressive axial loading results in bending and

angular displacement of the transcondylar screw as well as plate deformation.

Figure 4. Radiographs of (A&B) a Kirschner wire and (C&D) a reconstruction plate constructs obtained after mechanical testing. Note the bending and migration of the Kirschner wire as well as the angulation of the transcondylar screw and the gap at the articular surface in the Kirschner wire construct. In the reconstruction plate construct the transcondylar screw has angulated, but the proximal shaft of the screw has also bent. The reconstruction plate has bent but apposition of the osteotomy has been conserved more effectively than in the Kirschner wire construct.